APPLICATION NOTE

SEMICONDUCTOR PRODUCTS DEPARTMENT
SYRACUSE, NEW YORK | AUBURN, NEW YORK
AREA CODE 315 456-2396 | AREA CODE 315 253-7321

90.18
Rev.
5/64

A Tuned R.F. Stage High Performance Portable Broadcast Receiver Using Silicon Planar Passivated Transistors

by
Glen E. Snyder
and
Eugene L. Haas

This report is based on high performance obtained with the least number of transistors used at optimum conditions rather than a large transistor count. It is this author's opinion that transistors will follow the way of tubes in this respect.

The transistors used in this design are all epoxy housed silicon planar passivated transistors with the exception of the Class AB outputs which are planar passivated epitaxial transistors and have a small heat sink. The electrical characteristics of silicon and fundamental biasing considerations are mentioned in more detail in Application Note 90.8.

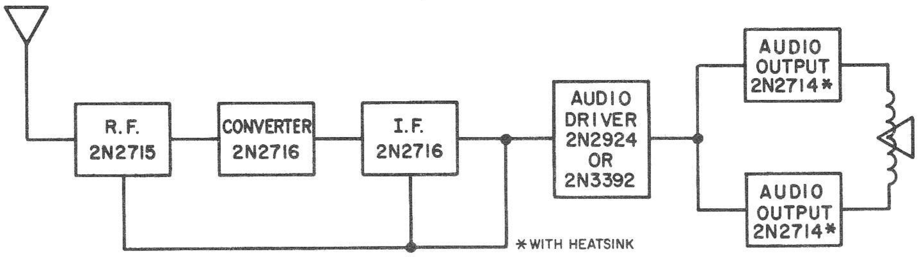
The circuit includes a tuned R. F. stage for extra sensitivity, selectivity and improved noise figure. It also provides another stage which can be gain controlled thus giving much better AVC action. It should be noted that the AVC action on the R. F. stage also results in an improved signal to noise ratio (ENSI)* at points higher than sensitivity level, because of the lowered current in the R. F. stage.

The half voltage performance is equal and possibly better than that obtained with germanium transistors due to the special biasing technique used on the low level stages and to the silicon diode added to the biasing circuit of the Class AB outputs. The diode tends to maintain the cross-over current and power output more nearly constant as the battery voltage decreases, and in addition provides temperature compensation superior to that obtained with a thermistor.

*Equivalent Noise Sideband Input. See Radiotron Designers Handbook or IRE Standards

No portion of this paper may be reproduced without prior written permission of the Semiconductor Products Department of the General Electric Company. The circuit diagrams included in this application note are for illustration of typical transistor applications and are not intended as constructional information. Although reasonable care has been taken in their preparation to assure their technical correctness, no responsibility is assumed by the General Electric Company for any consequences of their use.

Block Diagram (See Note on last page.)



Audio Output

This is the conventional output circuit used in all the silicon Class AB radio designs thus far. The planar passivated epitaxial transistor was again used because of its high gain, low saturation resistance, and very low Ico.

The load impedance is a 250Ω center-tapped transformer. The output power of this set will therefore be approximately:

R_{c-c} = collector to collector load resistance
R_{b-b} = base to base input resistance

$$P_o \cong \frac{2\,E_c^2}{R_{c-c}} = \frac{2 \times (8)^2}{250} \cong \frac{128}{250} \cong 510 \text{ mw}$$

$$I_{max} = \frac{4\,E_c}{R_{c-c}} = \frac{4 \times 8}{250} = 128 \text{ ma}$$

$$Z_{in} \cong R_{(b-b)} \cong (4h_{FE}\text{min at } I_{max}) \times (h_{ib} + R_e)$$

$$Z_{in} \cong 4 \times 60 \times (2\Omega + 3\Omega) \cong 240 \times 5 \cong 1200\Omega$$

h_{FE} (min at I_{max}) was estimated to be ≅ 60 due to h_{FE} fall off at 128 ma and h_{ib} was estimated to be approximately 2Ω.

$$\text{P.G. (min)} = \frac{2\,h_{FE}^2\ (\text{min})\ E_c^2}{Z_{in} \times P_o} = \frac{2 \times 3600 \times 64}{1200 \times .51} = 753 \cong 28.8 \text{ db}$$

When the Class AB output stage is biased to approximately 3 ma I_{cq}(quiescent current) to reduce cross over distortion, there would be too much loss in current in the resistor type of voltage divider when the bottom leg to ground is small and too much loss in power gain when this resistor is large. Also the bias voltage would be in direct proportion to the supply voltage and any large change (1/2 supply voltage) would give a large change in bias voltage and hence a large change in I_{cq}.

It was necessary to use a silicon diode in the base to ground leg of the output stage to get a good degree of control when the battery decreases towards half voltage. Control was excellent because the biasing diode has very much the same dynamic transfer characteristic as the output transistors, and with increasing temperature will automatically decrease the forward bias by 2 mv/°C to match the V_{BE} requirements of the output transistors.

Driver

The typical Class A driver stage uses the 2N2924 planar passivated transistor which has h_{fe} of 150 min - 300 max.

The load resistance of a Class A driver stage is determined by the maximum driving power necessary to drive the output stage to clipping before the driver stage can clip. This also includes transformer losses and overload capacity of 20%. The commercially economical driver and output transformers have efficiencies of approximately 80%.

$$P_{drive\ (max)} \cong \frac{1.2P_o\ (max)}{.8 \times .8\ PG} \cong \frac{1.2 \times 510 \times 10^{-3}}{.64 \times 753} \cong 1.27 \text{ mw}$$

The load resistance R_L of the driver:

$$R_L \cong \frac{E_c^2}{2\ P\ drive} \cong \frac{(6.5)^2}{2 \times 1.27 \times 10^{-3}} \cong 1.67 \times 10^4 = 16{,}700$$

The load resistance R_L of 16,700Ω would normally be used to get max gain of the driver stage with a fixed supply, but in this case we used ≈3 times lower impedance to maintain performance at half voltage. This will insure adequate power to drive the output stage to clipping before the driver. With the silicon planar transistors there is such an abundance of power gain available to the circuit designer that compromises of this nature can easily be afforded.

For output powers in the order of a few milliwatts, the load resistance is not negligible in comparison to the output impedance of the transistor, therefore, more exact equations must be used to determine the power gain of the Class A driver stage. From four terminal network theory, after making appropriate approximations, it can be shown that the voltage gain is given by the formula:

$$A_V = \frac{R_L}{h_{ib}} = \frac{5 \times 10^3}{12.5} = 4.0 \times 10^2$$

All h parameters were measured on minimum h_{fe} 2N2924 at 270 c.p.s. 2 ma I_c 4.5 volts Vc.

$$A_I \cong \frac{\alpha}{1-\alpha + R_L h_{ob}} = \frac{.9935}{1-.9935 + (5\times 10^3 \times .166\times 10^{-6})} \cong 1.36 \times 10^2$$

$$P.G. = A_I\ A_V = 4.0 \times 10^2 \times 1.36 \times 10^2 = 5.44 \times 10^4$$

$$P.G. = 47.35 \text{ db}$$

Output minimum P.G. 28.80 db

Driver minimum P.G. 47.35 db. The overall minimum gain of the audio system is 76.15 db.

Detector Stage

A silicon diode is forward biased to .54 volts in order to bring it to the threshold of conduction for detection. It is also used as the source of the AVC potential derived from the filtered portion of the signal as seen across the volume control. This potential which is proportional to the signal level is applied back to the base of the R. F. transistor and also to the base of the 1st I. F. transistor in a manner to decrease the collector current at increasing signal levels. The primary AVC action is on the RF stage since the IF, which is also an AVC amplifier, is never biased off. The RF stage, biased at .7 ma quiescent current in order to obtain good gain and be near the optimum point for best signal noise ratio, takes little power to get maximum AVC action. The action of the IF is an auxillary AVC for very large signal levels.

I.F.

The I.F. is unconventional only in that it simultaneously acts as an AVC amplifier and has AVC applied to it. The quiescent current of the I.F. is centered higher than normal because of this. The stage is biased to between 2.5 ma to 2.7 ma. Biasing is unusual since the detector diode forms a part of the bias network in a manner similar to that described in the section on output biasing. With a beta spread of 125-250, quiescent current change was only .2 ma.

Deliberate I.F. transformer mis-match was used to promote stability and also to present a lower impedance load line so as to get more undistorted I.F. power from this stage.

To calculate the approximate I.F. power gain unilateralized,

$$P.G.u. \cong \frac{\left| h_{21} \right|^2}{4\ h_{11(real)}\ h_{22(real)}}$$

The h_{21} and h_{11} parameters at 455 kc/s are obtained from the spec sheet for the typical 2N2716 in the unneutralized condition and represent fair approximations of the neutralized values. The h_{22} parameter is much more dependent on neutralizing and has to be calculated by converting low frequency parameters to 455 kc/s parameters in the neutralized condition where the effect of C_{ob} approaches zero.

$$\alpha_{bo} = .992 \qquad f\alpha_b = 100 \text{ mc/s} \qquad G_c = \frac{1}{r_c} = 2.38 \times 10^{-7} \text{ mhos}$$

$$h_{21} = 110 \angle\underline{-30^\circ}$$

$$h_{11} = 1760 \angle\underline{-29^\circ} = 1540 - j\ 854 \text{ ohms}$$

$$h_{22} = \frac{(G_c + j\ w_{cob}) \cdot \left(1 + \frac{j\ w}{w\alpha b}\right)}{(1 - \alpha bo) \left[1 + \frac{j\ w}{(1 - \alpha bo)\ w\alpha b}\right]}$$

$$h_{22} = \frac{(2.38 \times 10^{-7} + j\ o) \ \dfrac{(1 + j\ 4.55)}{1 \times 10^{3}}}{(1 - .992) \left[1 + \dfrac{j\ 4.55}{8}\right]}$$

$$h_{22} = 2.58 \times 10^{-5} \angle 60.4^{o} = 1.275 \times 10^{-5} + j\ 2.25 \times 10^{-5} \text{ mhos}$$

$$\text{P.G.u} = \frac{110^{\ 2}}{4 \times 1.54 \times 1.27 \times 10^{-2}}$$

$$\text{P.G.u} = 1.55 \times 10^{5} = 51.9 \text{ db}$$

The insertion loss of the I.F. transformer is 11.3 db, which includes impedance mismatch. Thus the useable I.F. power gain is approximately 40.6 db.

Converter

The converter is an "autodyne" stage in which the mixer is in the common emitter configuration and the oscillator is in the common base configuration. The only difference from the usual converter is that the secondary winding of the R. F. stage transformer takes the place of the antenna secondary. The secondary winding turns should be kept as low as possible to keep the base to ground impedance low so that the oscillator injection voltage is smooth with no amplitude modulation or regenerative "bumps". It is biased stably at 1ma and will operate down to one-half the supply voltage.

The typical conversion power gain is approximately 40 db minus the transformer insertion loss and transformer mis-match. The conversion power gain $\cong 40 - 12.8 \cong 27.2$ db.

R.F.

The R.F. stage is a common emitter amplifier to insure high gain, good signal to noise ratio, improved sensitivity and selectivity, and excellent AVC action.

The consistency of I_C over the specified beta range is again quite good because of the stabilization influence of the detector diode as described in the I.F. section.

The R.F. stage is biased at approximately .7 ma quiescent current by the AVC buss. As the input signal increases the AVC drives the base of the R.F. transistor toward zero thus turning the stage very nearly off at high signal levels. The majority of the AVC action is contributed by the R.F. stage, with the I.F. coming in mainly at very high signal levels.

At signal levels of 100 to 200 uv/meter, AVC action has already started on the R.F. stage, resulting in an ENSI ratio which improves with increasing signal strength, just the opposite of most radio receivers.

The power gain of this stage is similar to the I.F. Transformer mis-match is again used to hold the stage stable, along with high insertion loss ($\cong$ 10 db). The R.F. stage is operating in the unneutralized state and thus we have less stable power gain. The h parameters are all taken from the spec sheet for the typical 2N2715 at 455 Kc/s.

$$h_{21} = 82 \angle -22^{o} \qquad h_{11} = 1330 \angle -21^{o} \Omega = 1245 - j\ 476 \Omega .$$

$$h_{22} = 1870 \times 10^{-6} \angle 60^{o} \text{ mhos} = 935 \times 10^{-6} + j\ 1620 \times 10^{-6} \text{ mhos}$$

$$\text{P.G.} \cong \frac{\left|h_{21}\right|^{2}}{4\ h_{11(\text{real})}\ h_{22(\text{real})}} \cong \frac{82^{\ 2}}{4 \times 1.245 \times 9.35 \times 10^{-1}} = 1.45 \times 10^{3}$$

Power Gain = 31.6 db

Useable circuit power gain = 31.6 - 10 = 21.6 db.

PART DETAILS OF MAJOR IMPORTANCE

(see also parts list and schematic)

L_1 Ferrite rod antenna (7 3/8" long, 1/2" diameter). Primary 90 turns, secondary 6 turns bifilar wound. The tuned impedance of the antenna secondary is 415Ω at 600 Kc/s, 715Ω at 1000 Kc/s and 840Ω at 1400 Kc/s. Primary inductance is approximately 375 µ henries at 10 Kc/s. Q unloaded: 200 minimum when measured at 790 Kc/s.

L_2 A conventional oscillator coil, #1265 Ed Stanwyck Coil Company, with the "tickler" shunted to produce approximately 120 mv oscillator injection voltage.

C_a 235 µµfd max. - 17 µµfd min.

C_b 235 µµfd max - 17 µµfd min.

C_c 75.8 µµfd max - 16 µµfd min.

T_1 Single tuned (hand wound).
Primary -200 turns tapped at 30 turns. Secondary - bifilar start 20 turns.
Wire - 7 strands #44 core - ferrite 3/8" long, 1/4" diameter
(Measured--------@ 600 Kc/s)
Z_p = 1400Ω R_L= 1 KΩ Q_L = 40 I.L. = 10 db
3 db BW - 15 Kc/s x 2 BW - 28.8 Kc/s

T_2 Double tuned (hand wound).
Primary - 380 turns tapped at 50 turns. C=75 uufd.
Secondary - 400 turns tapped at 25 turns. C = 75 uufd.
Z_p = 4 KΩ R_L = 1 KΩ Q_L = 60 I.L. = 12.8 db 3db BW = 7.6 Kc/s
Cores - 7/16" long, 3/16" diameter
Material - ferrite
Windings - 3/8" apart Wire - 7 strands #44

T_3 Radio Industries #13964
Z_p = 1K R_L = 1K Q_L = 38 I.L. = 11.3db
Turns ratio - 1.4/1 x 2 BW = 20.7 Kc/s
Primary - 295 turns tapped at 35
Secondary - bifilar start 25 turns

TABLE I

Performance Data on Silicon Model #6T - 9V. with R.F. Stage
Reference Power Output: 50 mw
Reference Load Impedance 3 ohms
Supply Voltage (Ebb): 9 volts

		Full Supply Voltage		Half Supply Voltage	
Quiescent Collector Current (Icq):					
hFE					
45-90	R.F. Stage: 16D	.64 ma	.85 ma	.24 ma	.3 ma
75-150	Converter Stage: 16D	.62 ma	1.23 ma	.21 ma	.51 ma
125-250	I.F. Stage: 16D	2.5 ma	2.7 ma	1.1 ma	1.2 ma
hfe					
150-300	Driver Stage: 16A	1.7 ma	4.4 ma	.6 ma	1.5 ma
hFE					
100	Push-Pull Pair (for both) 16B	5.5 ma		2.1 ma	
	Total Drain from Battery:	12.5 ma			
	"BOGEY KIT"				
Audio (400 cps): (treble max)					
Maximum Power Output:		780 mw		165 mw	
Maximum Power Output at 10% Dist:		500 mw		120 mw	
Audio Sensitivity at Volume Control:		1.4 mv		5.3 mv	
Intermediate Frequency (455 Kc/s) 400 Cycle Mod:					
Sensitivity at Detector		20 mv		39 mv	
Sensitivity at I.F. Base		.46 mv		1.05 mv	
Sensitivity at Converter Base		29 µv		160 µv	
Radio Frequency: Sensitivity at Ant. Sec. 400 Cycle Mod:					
600 Kc/s		1.3 µv		21 µv	
1000 Kc/s		.95 µv		19 µv	
1400 Kc/s		1.2 µv		27 µv	

	Full Supply Voltage	Half Supply Voltage
Radio Frequency Range: 532 Kc/s - 1630 Kc/s		
Oscillator Injection Voltage at emitter: (mv)	100-121-115	17-37-36
Radio Frequency (Mod: 400 cycles)		
Radiated Sensitivity (Hazeltine at 24 in):		
at 600 Kc/s	40 µv/m	650 µv/m
at 1000 Kc/s	24 µv/m	250 µv/m
at 1400 Kc/s	22 µv/m	460 µv/m

Radiated Selectivity Tests:

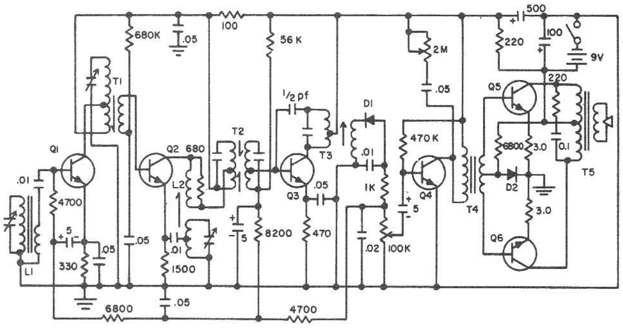
	at 600 Kc/s	at 1000 Kc/s	at 1400 Kc/s
X2	4.53 Kc/s	4.36 Kc/s	4.73 Kc/s
X10	10.1 Kc/s	11.7 Kc/s	12.1 Kc/s
X100	21.4 Kc/s	25.9 Kc/s	27.0 Kc/s
X1000	37 Kc/s	50 Kc/s	53.0 Kc/s

Noise Performance

	at 600 Kc/s		at 1000 Kc/s		at 1400 Kc/s	
	S/N	ENSI	S/N	ENSI	S/N	ENSI
Sens. Level	13 db	2.68	10 db	2.28	9.6 db	2.24
50 µv/m	15 db	2.65	17.5 db	2.0	17 db	2.12
100 µv/m	23.5 db	2.01	25 db	1.68	24 db	1.9
200 µv/m	30 db	1.9	30.7 db	1.76	29.7 db	1.97
500 µv/m	36 db	2.37	36.7 db	2.19	36.4 db	2.27

I.F. Rejection Ratio at 600 Kc/s	1600/1
Image Rejection Ratio at 1400 Kc/s	936/1
Image Rejection Ratio at 1000 Kc/s	8000/1
Image Rejection Ratio at 600 Kc/s	18,000/1

AVC Figure of Merit 63.5 db



GENERAL ELECTRIC CO.

Q1	2N2715
Q2, Q3	2N2716
Q4	2N2924 OR 2N3392
Q5, Q6	2N2714 (WITH HEAT SINK)
D1, D2	IN4009

RADIO INDUSTRIES, INC.

T1	16412
T2	16414
T3	13964
L1	16413
L2	16411

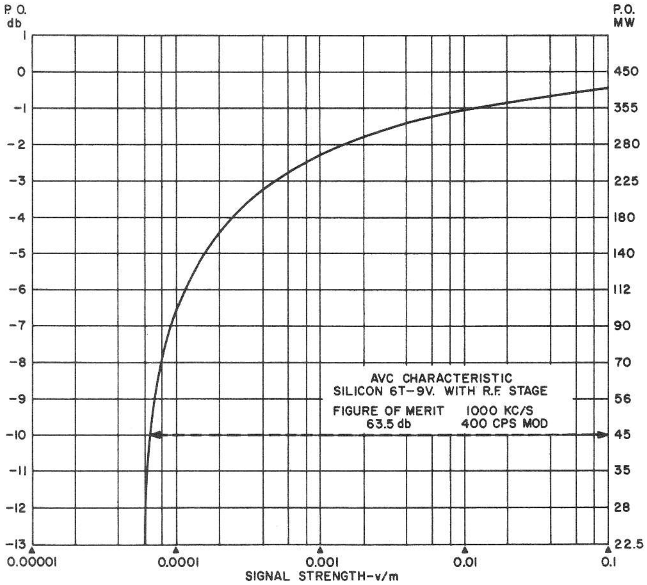
RADIO CONDENSER CORP.

TUNING CONDENSER
MODEL 42-3A (CN 909991)

PERFORMANCE	
NOMINAL SENSITIVITY	30µv/m
RATED OUTPUT POWER	500 MW
BATTERY DRAIN	12.5 MA

OTHER COMPONENTS

T4 5K/2K CT
T5 250 CT/VC



Note: Since the last revision of this Application Note, new and better transistors have become available. These devices provide a better signal to noise ratio and should be substituted as follows:

Old	New
2N2714	2N3402
2N2715	2N3855A
2N2716 (converter)	2N3858
2N2716 (I. F.)	2N3859